Experimental Measurements and Numerical Predictions of the Gasification of Finite Thickness Polymers

S.J. Ritchie and T. Kashiwagi
National Institute of Standards and Technology
Gaithersburg, MD 20899

During polymer combustion, there are two general processes that influence the burning rate of the material; the flame zone heat feedback to the polymer surface and the corresponding gasification rate of the polymer. The two processes are directly coupled. This study focuses on the condensed-phase processes which affect the gasification rate. Presented are the results of an experimental and numerical study into the influence of sample thickness and back surface boundary condition on the gasification rate of thermoplastic polymer materials under non-flaming conditions. Typically, the influence of thickness is ignored in theoretical developments because of the simplicity or convenience in assuming a semi-infinite material (ie. [1], [2]). However, in real applications of polymers, a semi-infinite analysis may be inappropriate.

Gasification experiments were carried out in a nitrogen gas environment with samples of polypropylene (PP) and polymethylmethacrylate (PMMA). The samples were 10.2 cm in dia and varied in thickness from 3 mm to 25.4 mm. Samples were subjected to incident fluxes of 30 and 50 kW/m^2 and the exposed and backside temperatures were measured with thermocouples. The samples were placed in a 10.2 cm dia. x (sample thickness + 6.4 mm) deep cavity which was cut into a 5.1 cm thk. x 12.7 cm dia. brick of foamglas insulation.

Numerical predictions were made using a one-dimensional model based on the classical Stefan problem for ablation that compensates for finite sample thickness and conductive losses to a backing substrate (also of finite thickness). The calculations required the solution of the heat equation in both the sample and the backing insulation. The two solutions were coupled at the interface using an energy balance and the continuity of temperature. The back boundary of the substrate was assumed to be adiabatic. The model has terms to compensate for the indepth absorption of the incident radiant energy and indepth degradation of the polymer material. The degradation is controlled by a finite rate chemical equation. The Arrhenius constants and reaction order were obtained using differential thermogravimetric analysis measurements at various heating rates [3]. Products generated indepth were assumed to be liberated from the sample immediately. The heat of vaporization was experimentally determined using a differential scanning calorimeter.

From a parametric study with the numerical model, the influence of the backing material on the gasification rate is clearly a function of the sample thickness. The predictions show that as sample thickness is increased, the gasification rate tends towards a semi-infinite solution. As the amount of material is reduced by the gasification process, the backside boundary condition eventually starts to influence the temperature gradient, which in turn alters the gasification rate. The exact nature of the change to the gasification rate depends on many factors which include: the relative material properties of the polymer and the backing material, the thickness of the backing material and the value of the externally applied flux. In the experiments, the conductivity of the backing material was much lower than that of the sample. Therefore the gasification rate rises very dramatically when the sample becomes thermally thin as shown in Figure 1 for the PMMA. For the 3.2 mm and 6.4 mm thick samples this influence is observed immediately, precluding any evaluation of material characteristics independent of the apparatus. For the thicker samples, such as 25.4 mm, the back boundary condition does not alter the results noticeably until the sample is very thin near the end of the gasification experiment. The quasi-steady portion of the gasification rate curve is a better measure of the materials response to heating because it is independent of the backing material (ie. apparatus independent). The numerical model predicts the observed experimental trends extremely well. Small differences in the absolute values between the model predictions and the experimental measurements can be attributed to processes that have not been fully considered in the numerical prediction such as: a conductive heat transfer contact resistance between the sample and the backing material, the transport of indepth degradation products through the polymer melt, and the variation of material properties with temperature and material characteristics. For example, when bubbles are trapped within a liquid melt layer the conductive and radiative heat transfer through the sample could be dramatically altered.

The results of this study impact the evaluation of cone calorimeter data and the application of polymer materials in many realistic applications. Often cone calorimeter data is presented in terms of a maximum heat release rate per unit area of burning material. However, this value is dependent upon the material used as a backing substrate and does not represent an independent material property. A more appropriate measure would be of the quasi-steady state value achieved using samples of much larger thicknesses (> 12 mm). Additionally, the gasification process of materials subjected to fire conditions in realistic applications will be influenced strongly by both the thickness of the material and the boundary conditions imposed.

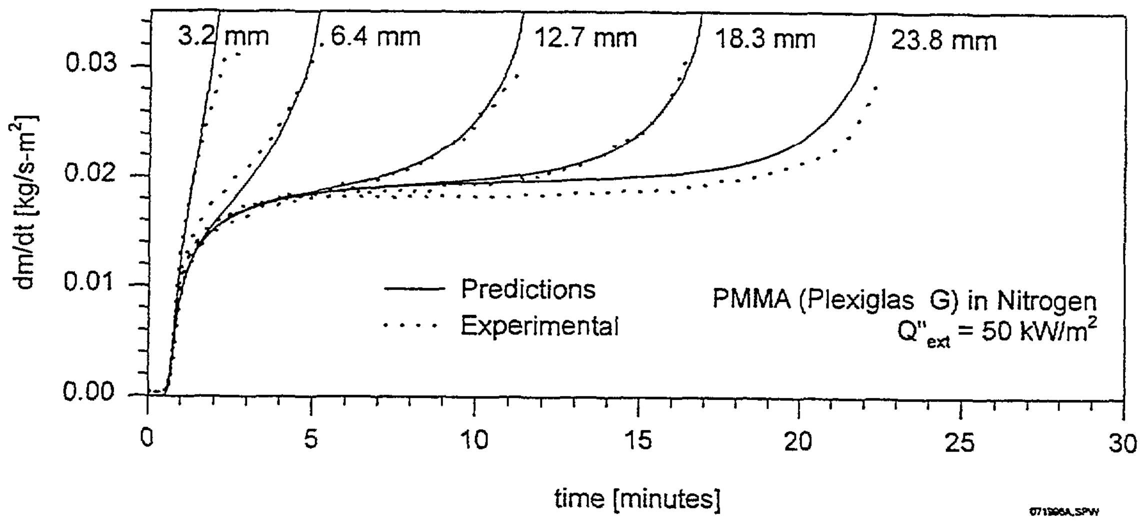

Figure 1. Gasification rate comparison of experimental measurements with numerical predictions for PMMA at various thicknesses when subjected to 50 kW/m^2 of external energy.

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